

This Page Is Inserted by IFW Operations  
and is not a part of the Official Record

## **BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images may include (but are not limited to):

- BLACK BORDERS
- TEXT CUT OFF AT TOP, BOTTOM OR SIDES
- FADED TEXT
- ILLEGIBLE TEXT
- SKEWED/SLANTED IMAGES
- COLORED PHOTOS
- BLACK OR VERY BLACK AND WHITE DARK PHOTOS
- GRAY SCALE DOCUMENTS

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning documents *will not* correct images,  
please do not report the images to the  
Image Problem Mailbox.**

(19)



Europäische Patentamt  
European Patent Office  
Office européen des brevets



(11)

**EP 0 964 237 A1**

(12)

**EUROPEAN PATENT APPLICATION**

published in accordance with Art. 158(3) EPC

(43) Date of publication:

15.12.1999 Bulletin 1999/50

(51) Int. Cl.<sup>6</sup>: **G01M 11/02**

(21) Application number: 98955951.3

(86) International application number:  
**PCT/JP98/05336**

(22) Date of filing: 27.11.1998

(87) International publication number:  
**WO 99/28723 (10.06.1999 Gazette 1999/23)**(84) Designated Contracting States:  
**DE FR GB**

(30) Priority: 28.11.1997 JP 32861297

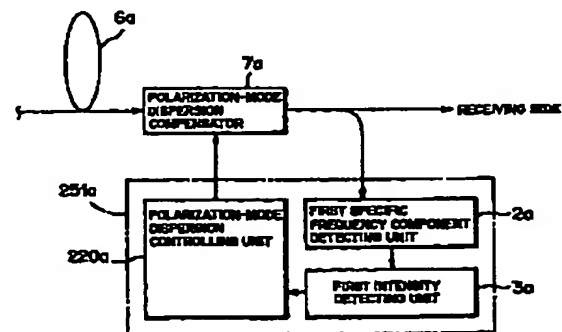
(71) Applicant: **FUJITSU LIMITED**  
Kawasaki-shi, Kanagawa 211-8588 (JP)

- ISHIKAWA, George,  
Fujitsu Limited  
Kawasaki-shi, Kanagawa 211-8588 (JP)
- AKIYAMA, Yuichi,  
Fujitsu Limited  
Kawasaki-shi, Kanagawa 211-8588 (JP)

(72) Inventors:  
• OOI, Hiroki,  
Fujitsu Limited  
Kawasaki-shi, Kanagawa 211-8588 (JP)(74) Representative: **HOFFMANN - EITLE**  
Patent- und Rechtsanwälte  
Arabellastrasse 4  
81925 München (DE)

(54) **POLARIZATION MODE DISPERSION MEASURING METHOD, AND A DISPERSION COMPENSATION CONTROL DEVICE AND A DISPERSION COMPENSATION CONTROL METHOD**

(57) A dispersion compensation controlling apparatus used in a very high-speed optical communication system adopting optical time division multiplexing system comprises a first specific frequency component detecting unit (2a) detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line (6a), a first intensity detecting unit (3a) detecting information on an intensity of the first specific frequency component detected by the first specific frequency component detecting unit (2a), and a polarization-mode dispersion controlling unit (220a) controlling a polarization-mode dispersion quantity of the transmission line (6a) such that the intensity of the first specific frequency component detected by the first intensity detecting unit (3a) becomes the maximum, thereby easily detecting and compensating polarization-mode dispersion generated in a high-speed optical signal.

**FIG. 1**

## Description

## TECHNICAL FIELD

[0001] The present invention relates to a polarization-mode dispersion detecting method, and a dispersion compensation controlling apparatus and a dispersion compensation controlling method used when polarization-mode dispersion or chromatic dispersion of a transmission optical signal which becomes a factor of limitation on a transmission distance of a high-speed optical signal in a very high-speed optical communication system adopting, for example, optical time division multiplexing.

## BACKGROUND ART

[0002] In a trunk-line optical communication system, a system with a transmission rate 10 Gb/s (gigabit/second) is in stage of practical application. On the other hand, there is a demand for a larger capacity of the optical communication system with a rapid increase of an information quantity. Considered as candidates for employable system are time division multiplexing (including optical time division multiplexing) and wavelength division multiplexing. Particularly, in time division multiplexing, a lot of researches on a very high-speed optical communication system with a transmission rate 40 Gb/s (hereinafter referred to as a 40 Gb/s optical communication system) are conducted inside and outside the country.

[0003] However, the 40 Gb/s optical communication system has a problem that a transmission distance of an optical signal is limited since a transmission waveform is deteriorated by effects of polarization-mode dispersion and chromatic dispersion. Namely, in this system transmission line, a chromatic dispersion value and a polarization-mode dispersion value are factors of limitations of a transmission rate and a transmission distance. Hereinafter, results of simulation and results of experiment on chromatic dispersion will be described with reference to FIGS. 66 through 72, and polarization-mode dispersion will be described with reference to FIGS. 73 through 75.

[0004] Although a term "dispersion" is generally used to mean "chromatic dispersion", when merely the term "dispersion" is used hereinafter, it means both "polarization-mode dispersion" and "chromatic dispersion" unless specifically mentioned.

[0005] First, chromatic dispersion will be schematically described. Since a chromatic dispersion tolerance (tolerance means an allowance) is inversely proportional to the square of a bit rate, a chromatic dispersion tolerance of 10 Gb/s is 800 ps/nm, while a chromatic dispersion tolerance of 40 Gb/s is about 50 ps/nm that is one sixteenth of 800 ps/nm, which is severer.

[0006] FIG. 66 shows a structure of an experimental system to evaluate dispersion compensation tolerance after 50 km transmission over a 1.3  $\mu\text{m}$  zero-dispersion fiber (SMF: Single Mode Fiber) in 40 Gb/s optical time division multiplexing (OTDM: Optical Time Division Multiplexing). Here are used a chromatic dispersion value = 18.6 ps/nm/km, and a total dispersion value = 930 ps/nm. A 40 Gb/s optical transmitter 121a shown in FIG. 66 is a signal light source. A signal light intensity-modulated in an intensity modulator 121b is inputted to a receiving side (hereinafter referred to as a receiving terminal, occasionally) over a DCF (Dispersion Compensating Fibers) 124 via the SMF 123. On the receiving side, a preamplifier 122a and a 40 Gb/s optical receiver 122b perform a demodulating process.

[0007] FIG. 67 shows a result of an evaluation experiment in this experimental system, wherein a transverse axis represents total dispersion quantity (unit: ps/nm) while a vertical axis represents power penalty (unit: dB). If here is required a power penalty 1 dB or less as an evaluation reference of the transmission line, a dispersion compensation tolerance (dispersion width) is 30 ps/nm, this value corresponding to 2 km or less in transmission using SMF. Namely, when a repeater spacing, that is, a distance between stations, is not constant as in a ground system, it is necessary to optimize a dispersion compensation quantity (high-accuracy dispersion, compensation of about 100%) of each repeater section.

[0008] Additionally, a chromatic dispersion value of an optical fiber transmission line changes with time with a change of laying environment such as temperature, pressure and the like. For example, in the case of a change in temperature from -50 to 100° C, a quantity of the change in dispersion of SMF 50 km is estimated to be 16 ps/nm as shown by the following formula:

$$\begin{aligned}
 &[\text{dispersion change quantity}] = [\text{temperature dependency of zero dispersion} \\
 &\text{wavelength}] \times [\text{temperature change}] \times [\text{dispersion slope}] \times [\text{transmission distance}] \\
 &= 0.03 (\text{nm}/^\circ\text{C}) \times 150 (^\circ\text{C}) \times 0.07 (\text{ps}/\text{nm}^2/\text{km}) \times 50 (\text{km}) \\
 &= 16 \text{ ps}/\text{nm}
 \end{aligned}$$

[0009] This value is more than a half of the dispersion tolerance 30 ps/nm, which has to be considered in full in system designing. The reason is that when a temperature becomes 100° C during system operation, the value does not meet

the reference of penalty 1 dB in the worst case, even if the dispersion compensation quantity is optimized at  $-50^{\circ}\text{C}$  when the operation of the system is started. Depending on characteristics or a structure of the dispersion compensator, it is impossible to continuously set a dispersion compensation quantity, so that there is a case where the dispersion compensation quantity can be set to only a value slightly deviated from an optimum value when the operation of the system is started. In this case, the value might not meet the reference of penalty 1 dB even with a change in temperature below  $150^{\circ}\text{C}$ .

[0010] In the above consideration, in order to realize a very high-speed optical communication system above 40 Gb/s, it is necessary to first optimize dispersion equalization (dispersion compensation quantity) in each repeater section when the system operation is started, and to secondary configure "an automatic dispersion equalization (compensation) system" optimizing dispersion equalization (dispersion compensation value) correspondingly to a change with time of a transmission line dispersion value even during the system operation. Meanwhile, this automatic dispersion equalization system is required not only in the SMF transmission system but also in the case where a  $1.55\text{ }\mu\text{m}$  wavelength dispersion shifted fiber (DSF: Dispersion Shifted Fiber) having a small chromatic dispersion value is used. Elemental techniques for realizing the automatic dispersion equalization system are summarized into three points, (a) through (c) below:

- (a) realization of a variable dispersion equalizer (compensator);
- (b) method of monitoring a chromatic dispersion value (or a total dispersion quantity after dispersion equalization [compensation]) of a transmission line; and
- (c) method of controlling feedback optimization of a variable dispersion equalizer (compensator).

[0011] As a method of measuring a chromatic dispersion value of an optical fiber, there has been used a pulse method or a phase method in which light having plural different wavelengths is inputted to an optical fiber, and a group delay difference or a phase difference in the output light is measured. However, in order to always measure dispersion during the system operation using these methods, a set of chromatic dispersion measuring devices are required in each repeater section. Further, in order to measure a dispersion quantity without interrupting transmission of data signal light, it is necessary to wavelength-multiplex measuring light having a wavelength different from that of the data signal light.

[0012] Assembling the pulse method or the phase method in an optical transmission apparatus is not realistic from the points of view of size and economy. Further, when a wavelength different from that of the main signal light, there is a possibility of lacking accuracy since it is necessary to perform a process to assume a dispersion value at a wavelength of the signal light from a measured value at a wavelength of the measuring light. For this, a method being able to directly monitor a wavelength dispersion value from the main signal light is desirable.

[0013] As this wavelength dispersion monitoring method, there has been already proposed in the Conference and the like a method using a 40 GHz component intensity in a baseband spectrum of a 40 Gb/s OTDM signal and an NRZ (Non-Return-to-Zero) signal.

[0014] FIG. 68 shows a relationship (simulation results) between 40 GHz component intensity and eye-opening with respect to dispersion quantity of a 40 Gb/s OTDM signal. Between two curves shown in FIG. 68, one having a pair of peaks represents 40 GHz component intensity, while the other one having a single peak represents eye-opening, wherein the minimum point between the pair of peaks of the 40 GHz component intensity is zero dispersion point, at which the eye-opening is the maximum.

[0015] FIG. 69 shows a structure of an experimental system at the time of DSF 100 km transmission. Signal light is sent from a transmitting side (hereinafter referred to as a transmitting terminal, occasionally) 131 shown in FIG. 69, and a temperature of a fiber that is a transmission line can be changed in a thermostat 133. On a receiving side 132, a 40 GHz component intensity is measured.

[0016] FIG. 70 shows results of the experiment in the experimental system, wherein a transverse axis represents signal light wavelength, while a vertical axis represents monitor voltage at a 40 GHz component intensity. The signal light wavelength that is the transverse axis is swept in a range from 1535 to 1565 nm [nanometer: (nano represents the minus ninth power of 10)], while the monitor voltage represents results at three kinds of temperatures. In each of these three kinds of waveforms, the minimum point between a pair of peaks of the waveform shows zero dispersion wavelength, like the simulation result shown in FIG. 68. Following a change in temperature ( $-35$  to  $+65^{\circ}\text{C}$ ) of DSF 100 km, it is known that the zero dispersion wavelength is changed ( $0.027\text{ nm}^{\circ}\text{C}$ ).

[0017] FIG. 71(a) shows a relationship (simulation results) between 40 GHz component intensity and eye-opening with respect to a dispersion quantity of a 40 Gb/s NRZ signal ( $\alpha = -0.7$ ). In FIG. 71(a), one having a plurality of peaks represents 40 GHz component intensity, while the other one having a single peak represents eye-opening, as well. In the case of  $\alpha < 0$ , the 40 Gb/s component intensity has the maximum peak in the vicinity of  $+30\text{ ps/nm}$ , and the monitor value shows zero that is the minimum value in zero dispersion at the foot on the negative dispersion's side.

[0018] FIG. 71(b) shows results of an experiment at the time of DSF 100 km transmission when a temperature is changed from  $-35$  to  $+65^{\circ}\text{C}$ . As well as the simulation results [refer to FIG. 71(a)], the minimum value at the foot on the

long wavelength' s side of the maximum peak [refer to a point denoted by 134 in FIG. 71 (b)] shows zero dispersion wavelength, and the zero dispersion wavelength is changed at  $0.026 \text{ nm/}^\circ\text{C}$ , which coincides with the results in FIG. 70. FIG. 71(a) shows simulation results in the case of a 40 Gb/s NRZ signal ( $\alpha = +0.7$ ). FIG. 72(b) shows simulation results in the case of a 40 Gb/s RZ (Return-to-Zero) signal ( $\alpha = 0$ , Duty = 50%). In such the automatic dispersion compensation system, it is necessary to feedback-control an operation point of a variable dispersion (equalization) compensator such that the eye-opening becomes the maximum using the above chromatic dispersion monitor.

[0019] Next, polarization-mode dispersion (PMD: Polarization-Mode Dispersion) that is the second factor having an effect on a transmission distance in the 40 Gb/s system will be schematically described. Polarization-mode dispersion (PMD) is caused by that propagation delay times of polarization components (light in two modes such as TE mode and TM mode, for example) of a light signal are different, which might generate in any optical fiber. Generally, the larger a transmission rate of an optical signal or the longer a transmission distance of an optical signal, the larger is an effect of polarization-mode dispersion, which cannot be ignored. It is said that some optical fibers configuring old optical transmission lines laid mainly in countries other than Japan have a large PMD value above  $1 \text{ ps/km}^{1/2}$  [pico second/km<sup>1/2</sup> (pico represents minus twelfth power of 10) per unit length. In the case of a short distance transmission (for example, 50 km transmission) using such optical fibers, an optical delay difference ( $\Delta\tau$ ) is 7 ps or larger per one time slot 25 ps of 40 Gb/s, where an effect of polarization-mode dispersion cannot be ignored. Incidentally, this value is determined according to a type of optical fiber, which does not depend on a transmission rate of an optical signal. Further, since it is practically necessary to provide devices generating polarization-mode dispersion such as an optical amplifier, a wavelength dispersion compensator and the like in an optical communication system, a transmission distance of an optical signal is further limited.

[0020] Accordingly, in order to increase a transmission rate of an optical signal while still using an optical transmission line having been already laid or perform long-distance in-line repeater transmission while still using an optical transmission line having been already laid, a technique of compensating polarization-mode dispersion generated in a transmit optical signal is demanded.

[0021] As methods of compensating polarization-mode dispersion, there are compensating methods described in publications shown below, for example. Incidentally, it is difficult to thoroughly compensate transmit waveform deterioration since mode coupling due to fluctuation of birefringence in a longitudinal direction of an optical fiber is complicatedly generated even with an optical fiber configuring an actual optical transmission line, moreover, the mode coupling is changed with time due to temperature change and the like. In order to relieve transmission waveform deterioration, methods described in publications ① through ③ shown below are effective.

① Method of providing a polarization controller (PC: Polarization Controller) at a transmitting terminal of an optical signal, feeding back transmission characteristic from the receiving terminal so as to control a splitting ratio  $\gamma$  of an optical intensity to two polarization modes to be 0 or 1 (J.H. Winters et al., "Optical equalization of polarization dispersion", SPIE Vol.1787 Multigigabit Fiber Communications, 1992, pp.346-357).

② Method of providing a polarization controller and a polarization maintaining fiber (PMF: Polarization Maintaining Fiber) at a receiving terminal of an optical signal, and controlling the polarization controller to give a delay difference (fixed value) between two polarization modes of an inverse code to an optical transmission line (T. Takahashi et al., "Automatic compensation technique for timewise fluctuating polarization-mode dispersion in in-line amplifier systems", Electro.Lett., vol.30, No.4, 1994, pp.348-349); and

③ Method of providing a polarization controller, a polarization beam splitter (PBS: Polarization Beam Splitter), photo receivers receiving two optical signal components split by the polarization beam splitter, and a variable delay element giving a delay difference between two electric signals obtained by the photo receivers to control the polarization controller and the variable delay element (T. Ono et al., "Polarization Control Method for Suppressing Polarization-mode Dispersion Influence in Optical Transmission Systems", J. of Lightwave Technol., vol.12, no.5, 1994, pp.891-898).

[0022] In any of these methods ① through ③, it is necessary to detect a state of polarization-mode dispersion at a receiving terminal of an optical signal to perform a feed-back control. However, there is required not a complicated method using a result of detection of a code error rate or the like but a technique of easily detecting a state of polarization-mode dispersion. Such an optical communication systems will be required in future that a bit rate, a transmission distance, a signal modulation format and the like can be freely changed. For this, even in a technique of compensating polarization-mode dispersion, it is required to comply with fluctuations of a state of polarization-mode dispersion generated in a transmission line.

[0023] FIG. 73 shows an experimental system for studying transmission waveform deterioration of a 40 Gb/s signal by PMD. An optical intensity splitting ratio (or an optical power ratio)  $\gamma$  of each polarization component of signal light sent out from a transmitting side 133 shown in FIG. 73 is changed in a polarization controller 134, the signal light is added PMD generated in a transmission line in a PMD emulator (PMD emulator) 135 and demodulated in a receiving terminal

136. The PMD emulator 135 simulates PMD generated in the transmission line, wherein a commercially available PMD emulator is used. Principles upon which the PMD emulator 135 operates are as follows. Namely, the signal light is split into two polarization components by the polarization beam splitter (PBS) 135a shown in FIG. 73, one of which is given an optical delay difference  $\Delta\tau$  (ps) in an optical delay device 135b, the other of which is given a loss in an optical attenuator 135 such that optical losses in the both optical paths are equal. Further, they are multiplexed while they are still in an orthogonal state by a polarization beam splitter (PBS) 135d. The output signal is amplified by an optical preamplifier 136a in the receiving terminal 136, and demodulated in an optical DEMUX (Demultiplex) 136b.

[0024] FIG. 74 shows results of an experiment of evaluation of power penalty to optical delay difference  $\Delta\tau$  of a 40 Gb/s OTDM signal and a NRZ signal. The transversal axis represents optical delay difference  $\Delta\tau$ , while a vertical axis represents power penalty. Incidentally,  $\gamma$  is set to 0.5 in the polarization controller 134 (refer to FIG. 73) such that transmission waveform deterioration is the maximum. A curved line denoted by (a) in FIG. 74 represents transmission waveform deterioration of the OTDM signal. When a reference value of receiver sensitivity degradation (power penalty [vertical axis]) is below 1 dB, a PMD allowable value (PMD tolerance) is 9 ps. A curved line denoted by (b) in FIG. 74 represents transmission waveform deterioration of the 40 Gb/s NRZ signal. When a reference value of receiver sensitivity degradation at this time is below 1 dB, the PMD allowable value (PMD tolerance) is 11 ps.

[0025] In consideration of a value of the receiver sensitivity degradation, some relatively old fibers having been already laid have a large PMD value above 1.0 ps/km<sup>1/2</sup> per unit length. In such case, a value of the receiver sensitivity degradation is above 10 ps even in a relatively short distance transmission of 100 km or less. Further, since polarization-mode dispersion is generated even in an optical amplifier, a chromatic dispersion compensator and the like other than a transmission line fiber in an actual optical transmission system, a transmission distance is further limited. In order to increase a transmission distance in a fiber transmission line having been already laid, or in order to perform long-distance in-line repeater transmission, "PMD compensating technique" is required. However, this compensating technique has three problems (d) through (f) below.

(d) realization of a PMD compensating device;

(e) method of detecting a PMD state (optical delay difference  $\Delta\tau$  and optical intensity splitting ratio  $\gamma$ ); and

(f) method of controlling feedback-optimization of a PMD compensating device.

[0026] Although a PMD measuring device has been commercially available, introducing such PMD measuring device as a part of an optical transmission system is not realistic in the view of size and economy. A method being able to directly monitor a PMD value is desirable. As such method, there is a method using a frequency component intensity in a baseband spectrum of a received signal, which is theoretically determined as below.

[0027] Assuming that  $F(t)$  is a change of an optical intensity with time when PMD is not given, a change of an optical intensity with time when PMD (optical delay difference  $\Delta\tau$  and optical density splitting ratio  $\gamma$ ) is given by the following formula:

$$\gamma F(t-\Delta\tau) + (1-\gamma)F(t)$$

[0028] An electric field intensity of an electric signal having been received is proportional to its value, and the square of the value is detected as a change of the intensity with time by the intensity detector. Baseband spectrum  $P(f)$  is expressed as its Fourier transform by the following formula (11):

$$\begin{aligned} P(f) &= |\{\gamma F(t-\Delta\tau) + (1-\gamma)F(t)\} \cdot \exp(i\omega t) dt|^2 \\ &= |\gamma F(t-\Delta\tau) \exp(i\omega t) dt + (1-\gamma) F(t) \exp(i\omega t) dt|^2 \\ &= |\gamma \exp(i\omega \Delta\tau) F(t) \exp(i\omega t) dt + (1-\gamma) F(t) \exp(i\omega t) dt|^2 \\ &= K(f) \cdot |F(t) \exp(i\omega t) dt|^2 \end{aligned} \quad (11)$$

wherein a factor of proportionality  $K(f)$  is expressed as below, and  $\omega = 2\pi f$ .

$$\begin{aligned} K(f) &= |\gamma \exp(i\omega \Delta\tau) + (1-\gamma)|^2 \\ &= |\gamma \{\cos(\omega \Delta\tau) + i \sin(\omega \Delta\tau)\} + (1-\gamma)|^2 \\ &= 1 - 4\gamma(1-\gamma) \sin^2(\pi f \Delta\tau) \end{aligned} \quad (12)$$

[0029] In formula (11), parameters (optical delay difference  $\Delta\tau$  and optical intensity splitting ratio  $\gamma$ ) relating to a PMD state are included in only  $K(f)$ , and separated from the baseband spectrum  $|F(t) \exp(i\omega t) dt|^2$  in the case of no PMD. When a frequency component  $f = f_e(\text{Hz})$  is extracted by a filter or the like and an intensity thereof is detected, depend-

ency on optical delay difference  $\Delta\tau$  and the optical intensity splitting ratio  $\gamma$  is expressed by  $K(f_e)$ . Moreover, from that the formula (11) is established for a general formula  $F(f)$  representing an optical waveform, the above result that the PMD state can be detected with  $K(f_e)$  is established irrespective of a modulating system (NRZ or RZ) or a waveform change due to such as wavelength dispersion, nonlinear effect or the like.

[0030] FIG. 75 shows a result of an experiment showing  $\Delta\tau$  dependency of 20 GHz components intensity in a 40 Gb/s NRZ system in the case of  $\gamma = 0.5$ . In this intensity detecting method, an optical signal is converted into an electric signal using a photo receiver (PD) in the receiving terminal, a signal of a 20 GHz component is extracted by a 20 GHz narrow-band band-pass filter (BPF), and an intensity is detected by a power meter. As shown in FIG. 75, the intensity is the maximum at optical delay difference  $\Delta\tau = 0$  ps, decreases with increasing the optical delay difference  $\Delta\tau$ , and becomes zero at the optical delay difference  $\Delta\tau = 25$  ps.

[0031] Using that the  $f_e$  (Hz) component intensity is the maximum when the PMD state is the best, a method of feed-back-controlling the polarization-mode dispersion compensator controlling the optical delay difference  $\Delta\tau$  and the optical intensity splitting ratio  $\gamma$  inserted in the optical transmission line (transmitting terminal, optical repeater and receiving terminal) according to a PMD monitor signal is possible.

[0032] Incidentally, there are publications relating to equalization as shown in ④ through ⑥ below.

④ publications relating to variable dispersion (equalization) compensator:

- R.I. Laming et al., "A Dispersion Tunable Grating in a 10-Gb/s 100-200-km-Step IndexFibe Link", IEEE Photon. Technol. Lett., vol.8, pp.428-430, 1996. (being able to vary a dispersion compensation quantity by changing a temperature slope in a longitudinal direction of a chirped fiber grating);
- M.M. Ohm et al., "Tunable fiber grating dispersion using a piezoelectric stack", OFC'97 WJ3. (being able to vary a dispersion compensation quantity by changing a stress in a longitudinal direction of a chirped fiber grating);
- K. Takiguchi et al., "Planar Lightwave Circuit Optical Dispersion Equalizer", IEEE Photon. Technol., Lett., vol.6, no.1, pp.86-88 (PLC variable dispersion compensator);
- A. Sano et al., "Automatic dispersion equalization by monitoring extracted-clockpower level in a 40-Gbit/s, 200-km transmission line" ECOC'96 TuD.3.5 (discreet variable dispersion compensator in which fibers having a positive or negative dispersion value are cascade-connected by a 1x4 mechanical switch);

⑤ publications relating to automatic dispersion equalizing system:

- G. Ishikawa and H. Ooi, "Demonstration of automatic dispersion equalization in 40-Gbit/s OTDM transmission," ECOC'98 WdCO6. (introduced in September 29, 1998);
- Ooi, Akiyama and Ishikawa, "Experiment on 40 Gbit/s automatic dispersion equalization using a wavelength tunable laser", EIC. Soc., 1998 (introduced in September, 30, 1998);
- M. Tomizawa et al., "Automatic Dispersion Equalization for Installing High-Speed Optical Transmission Systems", J. Lightwave Technol., vol.16, no.2, pp.184-191;

⑥ publications relating to automatic PMD compensating system:

- H.Ooi, Y.Akiyama, G.Ishikawa, "Automatic polarization-mode dispersion compensation in 40-Gbit/s transmission" (tentative title), submitted to OFC'99 (method of using a polarization controller(PC: Polarization Controller) and a polarization maintaining fiber (PMF: Polarization Maintaining Fiber) in a receiving terminal to control PC in a 40 Gb/s NRZ system, thereby giving a delay difference of an Inverse code to a transmission line);
- J.H. Winters et al., "optical equalization of polarization dispersion", SPIE Vol.1787 Multigigabit Fiber Communications, 1992 00.346-357 (method of using a polarization controller in a transmitting terminal, feeding-back the transmission characteristic from a receiving terminal to control in such a direction as  $\gamma = 0$  or 1);
- T. Takahashi et al., "Automatic compensation technique for timewise fluctuating polarization-mode dispersion in in-line amplifier systems", Electron. Lett., vol.30, no.4, 1994, pp.348-349 (method of giving a delay difference of an inverse code to a transmission line by using a polarization controller (PC) and a polarization maintaining fiber (PMF) in a receiving terminal to control PC), wherein a 5 GHz component intensity in a baseband spectrum of a 10Gb/s NRZ signal is detected and a control is performed such that the intensity becomes the maximum;
- T. Ono et al., "Polarization Control Method for Suppressing Polarization-mode Dispersion Influence in Optical Transmission Systems", J. Lightwave Technol., vol.12, no.5, 1994, pp.891-898 (method of using a polarization controller, a polarization beam splitter, photo receivers for respective light paths and a variable delay element giving a delay difference between both electric signals to control the PC and the variable delay element).



[0033] In the light of the above problems, an object of the present invention is to provide a polarization-mode dispersion quantity detecting method in which polarization-mode dispersion generated in a high-speed optical signal can be easily detected and monitored, a dispersion compensation controlling method in which these detected polarization-mode dispersion and chromatic dispersion can be compensated, thereby enabling a long-distance transmission of a high-speed optical signal, and a dispersion compensation controlling apparatus for simultaneously compensating transmission optical waveform deterioration caused thereby using the polarization-mode dispersion quantity detecting method and the chromatic dispersion detecting method.

# DISCLOSURE OF INVENTION

[0034] Therefore, a dispersion compensation controlling apparatus of this invention comprises a first specific frequency component detecting unit for detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line, a first intensity detecting unit for detecting information on an intensity of the first specific frequency component detected by the first specific frequency component detecting unit, and a polarization-mode dispersion controlling unit for controlling a polarization-mode dispersion quantity of the transmission line such that the intensity of the first specific frequency component detected by the first intensity detecting unit becomes the maximum.

[0035] Accordingly, it is thereby possible to compensate polarization-mode dispersion so as to prevent deterioration of a transmission waveform of an optical signal. This advantageously contributes to long-distance transmission of a high-speed optical signal.

[0036] Further, a dispersion compensation controlling apparatus of this invention comprises a first specific frequency component detecting unit for detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line, a first intensity detecting unit for detecting information on an intensity of the first specific frequency component detected by the first specific frequency component detecting unit, a polarization-mode dispersion controlling unit for controlling a polarization-mode dispersion quantity of the transmission line such that the intensity of the first specific frequency component detected by the first intensity detecting unit becomes the maximum, a second specific frequency component detecting unit for detecting a second specific frequency component in the baseband spectrum in the transmission optical signal, a second intensity detecting unit for detecting information on the intensity of the second specific frequency component detected by the second specific frequency component detecting unit, and a chromatic dispersion controlling unit for controlling a chromatic dispersion quantity of the transmission line such that the intensity of the second specific frequency component detected by the second specific frequency intensity detecting unit becomes the maximum.

[0037] Accordingly, it is thereby possible to compensate polarization-mode dispersion to prevent deterioration of a transmission waveform of an optical signal. It is also possible to compensate chromatic dispersion of a transmission optical signal, so as to prevent deterioration of the transmission waveform of the optical signal by effects of polarization-mode dispersion and chromatic dispersion. This more advantageously contributes to long-distance transmission of a high-speed optical signal.

[0038] Still further, a dispersion compensation controlling apparatus of this invention comprises a first specific frequency component detecting unit for detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line, a first intensity detecting unit for detecting information on an intensity of the first specific frequency component detected by the first specific frequency component detecting unit, a polarization-mode dispersion controlling unit for controlling a polarization-mode dispersion quantity of the transmission line such that the intensity of the first specific frequency component detected by the first intensity detecting unit becomes the maximum, and a chromatic dispersion controlling unit for controlling a chromatic dispersion quantity of the transmission line such that the intensity of the first specific frequency component detected by the first intensity detecting unit becomes the maximum or the minimum.

[0039] Accordingly, it is thereby possible to compensate polarization-mode dispersion to prevent deterioration of a transmission waveform of an optical signal. It is also possible to compensate chromatic dispersion of a transmission optical signal, so as to prevent deterioration of the transmission waveform of the optical signal by effects of polarization-mode dispersion and chromatic dispersion. This more advantageously contributes to long-distance transmission of a high-speed optical signal.

[0040] A polarization-mode dispersion quantity detecting method of this invention comprises the steps of a specific frequency component detecting step of detecting a specific frequency component in a baseband spectrum in a transmission optical signal inputted over a transmission optical fiber, an intensity detecting step of detecting an intensity of the specific frequency component detected at the specific frequency component detecting step, and a dispersion quantity detecting step of detecting a polarization-mode dispersion quantity of the transmission optical signal from information on the intensity of the specific frequency component detected at said intensity detecting step by performing a predetermined functional operation.



[0041] Accordingly, it is thereby possible to easily detect polarization-mode dispersion generated in a transmission optical signal.

[0042] In addition, a dispersion compensation controlling method of this invention comprises the steps of a first specific frequency component detecting step of detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line, a first intensity detecting step of detecting information on an intensity of the first specific frequency component detected at the first specific frequency component detecting step, and a polarization-mode dispersion controlling step of controlling a polarization-mode dispersion quantity of the transmission line such that the intensity of the first specific frequency component detected at the first intensity detecting step becomes the maximum.

[0043] Accordingly, it is thereby possible to easily detect polarization-mode dispersion generated in a transmission optical signal.

[0044] Further, a dispersion compensation controlling method comprises the steps of a first specific frequency component detecting step of detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line, a first intensity detecting step of detecting information on an intensity of the first specific frequency component detected at the first specific frequency component detecting step, a polarization-mode dispersion controlling step of controlling a polarization-mode dispersion quantity of the transmission line such that the intensity of the first specific frequency component detected at the first intensity detecting step becomes the maximum, a second specific frequency component detecting step of detecting a second specific frequency component in the baseband spectrum in the transmission optical signal, a second intensity detecting step of detecting information on an intensity of the second specific frequency component detected at the second specific frequency component detecting step, and a chromatic dispersion controlling step of controlling a chromatic dispersion quantity of the transmission line such that the intensity of the second specific frequency component detected at the second intensity detecting step becomes the maximum or the minimum.

[0045] Accordingly, it is thereby possible to perform the controls independently and simultaneously.

[0046] Still further, a dispersion compensation controlling method of this invention comprises the steps of a first specific frequency component detecting step of detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line, a first intensity detecting step of detecting information on an intensity of the first specific frequency component detected at the first specific frequency component detecting step, a polarization-mode dispersion controlling step of controlling a polarization-mode dispersion quantity of said transmission line such that the intensity of the first specific frequency component detected at the first intensity detecting step becomes the maximum, and a chromatic dispersion controlling step of controlling a chromatic dispersion quantity of the transmission line such that the intensity of the first specific frequency component detected at the first intensity detecting step becomes the maximum or the minimum.

[0047] Accordingly, it is thereby possible to prevent deterioration of a transmission waveform of an optical signal by effects of polarization-mode dispersion and chromatic dispersion, which further contributes to long-distance transmission of a high-speed optical signal.

#### BRIEF DESCRIPTION OF DRAWINGS

[0048]

FIG. 1 is a diagram showing a structure of a first basic block of this invention;

FIG. 2 is a diagram showing a structure of a second basic block of this invention;

FIG. 3 is a diagram showing a structure of a third basic block of this invention;

FIG. 4 is a block diagram showing a structure of an optical transmission system to which dispersion compensation controlling apparatus according to a first embodiment of this invention is applied;

FIG. 5 is a diagram showing a structure of a delay quantity compensator;

FIG. 6 is a diagram showing a structure of an experimental system of a 40 Gb/s optical time division multiplexing transmission system according to the first embodiment of this invention;

FIG. 7 is a diagram showing a structure of a PMD emulator;

FIGS. 8(a) through 8(e) are diagrams showing deteriorated 40 Gb/s optical time division multiplexed waveforms when the PMD emulator changes an optical delay difference  $\Delta\tau$  and gives it thereto;

FIG. 9 is a diagram for illustrating a method of detecting a polarization-mode dispersion quantity generated in a transmission optical signal;

FIGS. 10(a) and 10(b) are diagrams for illustrating a method of detecting a polarization-mode dispersion quantity generated in a transmission optical signal;

FIG. 11 is a diagram showing a structure of an experimental system of a 10 Gb/s NRZ transmission system according to the first embodiment of this invention;

[0512] As the delay quantity compensator described in the first embodiment, a delay quantity compensator 4A' shown in FIG. 65 may be used, other than one shown in FIG. 5. The delay quantity compensator 4A' is a delay quantity compensator whose delay quantity is variable. As shown in FIG. 65, the delay quantity compensator 4A' comprises a polarization controller 4A-2, polarization beam splitters (PBS: Polarization Beam Splitter) 4A-5 and 4A-6 and a variable optical delay 4A-7.

[0513] The polarization controller 4A-2 such controls that polarization-mode primary axis component of two transmission paths are TE and TM polarized waves, which comprises a  $1/4$  wave plate ( $\lambda/4$  plate) 4A-21, a  $1/2$  wave plate ( $\lambda/2$  plate) 4A-22 and actuators 4A-23 and 4A-24. The polarization beam splitter 4A-5 splits an optical signal inputted via the polarization controller 4A-2 into two. The variable optical delay 4A-7 variably gives a delay difference to one of the optical components split by the polarization beam splitter 4A-5. The polarization beam splitter 4A-6 multiplexes an optical component from the polarization beam splitter 4A-5 and an optical component from the polarization beam splitter 4A-7.

[0514] The actuators 4A-23 and 4A-24 configuring the polarization controller 4A-2, and the variable optical delay 4A-7 receive parameter setting control signals from the parameter setting circuit 15. The optimal control as the delay quantity compensator 4A' is performed on a polarization direction in the polarization controller 4A-2 and a delay difference to be given by the variable optical delay 4A-7.

[0515] In each of the embodiments described above, the polarization-mode dispersion compensator or the chromatic dispersion compensator is disposed in the optical transmitter or the optical receiver. However, this invention is not limited to the above examples, but they may be disposed in a repeating apparatus repeating a transmission optical signal. In such case, the parameter setting circuit or the chromatic dispersion compensation quantity setting circuit outputs each control signal to the polarization-mode dispersion compensator or the chromatic dispersion compensator disposed in the above repeating apparatus.

#### INDUSTRIAL APPLICABILITY

[0516] As having been fully described, the polarization-mode dispersion quantity detecting method of this invention has an advantage that an intensity of a specific frequency component in a baseband spectrum in a transmission optical signal is detected, and a polarization-mode dispersion quantity of the transmission optical signal is detected from the detected intensity of the specific frequency component by performing a predetermined functional operation or in a maximum value control, thereby easily detecting polarization-mode dispersion generated in the transmission optical signal.

[0517] According to this invention, a polarization-mode dispersion quantity is detected and polarization-mode dispersion generated in a transmission optical signal is compensated on the basis of the detected polarization-mode dispersion quantity, whereby deterioration of a transmission waveform of an optical signal is prevented. This contributes to realization of long-distance transmission of a high-speed optical signal.

[0518] According to this invention, a polarization-mode dispersion quantity is detected, polarization-mode dispersion generated in a transmission optical signal is compensated on the basis of the detected polarization-mode dispersion quantity, a chromatic dispersion quantity is also detected, and chromatic dispersion generated in the transmission optical signal is compensated on the basis of the detected chromatic dispersion quantity, whereby deterioration of a transmission waveform of an optical signal due to polarization-mode dispersion and chromatic dispersion is prevented. This contributes to realization of long-distance transmission of a high-speed optical signal.

#### Claims

1. A polarization-mode dispersion quantity detecting method comprising the steps of:

a specific frequency component detecting step of detecting a specific frequency component in a baseband spectrum in a transmission optical signal inputted over a transmission optical fiber;  
an intensity detecting step of detecting an intensity of said specific frequency component detected at said specific frequency component detecting step; and  
a dispersion quantity detecting step of detecting a polarization-mode dispersion quantity of said transmission optical signal from information on the intensity of said specific frequency component detected at said intensity detecting step by performing a predetermined functional operation.

2. The polarization-mode dispersion quantity detecting method according to claim 1, wherein said predetermined functional operation is performed at said dispersion quantity detecting step using a function which is a function representing an intensity of a frequency component in a baseband spectrum in an optical waveform forming an arbitrary transmission optical signal and in which said frequency information and parameters showing a polarization-mode dispersion quantity are variables.

3. The polarization-mode dispersion quantity detecting method according to claim 1, wherein said specific frequency at which the component is detected at said specific frequency component detecting step is set to a frequency at which a component in a baseband spectrum in said transmission optical signal can be stably obtained with respect to time.

4. The polarization-mode dispersion quantity detecting method according to claim 3, wherein when said transmission optical signal is an RZ optical signal or an optical time division multiplex signal, said specific frequency at which the component is detected at said specific frequency component detecting step is set to a frequency corresponding to a bit rate.

5. The polarization-mode dispersion compensating method according to claim 3, wherein when said transmission optical signal is in any optical modulation system, said specific frequency at which the component is detected at said specific frequency component detecting step is set to a frequency corresponding to 1/2 of a bit rate.

6. A dispersion compensation controlling apparatus comprising:

a first specific frequency component detecting unit (2a; 12) for detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line (6a; 3);

a first intensity detecting unit (3a; 13) for detecting information on an intensity of said first specific frequency component detected by said first specific frequency component detecting unit (2a; 12); and

a polarization-mode dispersion controlling unit (220a; 90) for controlling a polarization-mode dispersion quantity of said transmission line (6a; 3) such that the intensity of said first specific frequency component detected by said first intensity detecting unit (3a; 13) becomes the maximum.

7. The dispersion compensation controlling apparatus according to claim 6, wherein when said transmission optical signal is an RZ signal or an optical time division multiplex signal, said first specific frequency component detecting unit (2a; 12) detects a frequency corresponding to a bit rate as said first specific frequency component.

8. The dispersion compensation controlling apparatus according to claim 6, wherein when said transmission optical signal is in any optical modulation system, said first specific frequency component detecting unit (2a; 12) detects a frequency corresponding to 1/2 of a bit rate as said first specific frequency component.

9. A dispersion compensation controlling apparatus comprising:

a first specific frequency component detecting unit (2a; 79A) for detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line (6a; 73);

a first intensity detecting unit (3a; 80A) for detecting information on an intensity of said first specific frequency component detected by said first specific frequency component detecting unit (2a; 79A);

a polarization-mode dispersion controlling unit (220a; 91) for controlling a polarization-mode dispersion quantity of said transmission line (6a; 73) such that the intensity of said first specific frequency component detected by said first intensity detecting unit (3a; 80A) becomes the maximum;

a second specific frequency component detecting unit (222a; 79B) for detecting a second specific frequency component in the baseband spectrum in said transmission optical signal;

a second intensity detecting unit (223a; 80B) for detecting information on the intensity of said second specific frequency component detected by said second specific frequency component detecting unit (222a; 79B); and

a chromatic dispersion controlling unit (224a; 240) for controlling a chromatic dispersion quantity of said transmission line (6a; 73) such that the intensity of said second specific frequency component detected by said second specific frequency intensity detecting unit (223a; 80B) becomes the maximum or the minimum.

10. The dispersion compensation controlling apparatus according to claim 9, wherein when said transmission optical signal is an NRZ optical signal, said first specific frequency component detecting unit (2a; 79A) detects a frequency corresponding to 1/2 of a bit rate as said first specific frequency component; and

said second specific frequency component detecting unit (222a; 79B) detects a frequency corresponding to the bit rate as said second specific frequency.

## 11. A dispersion compensation controlling apparatus comprising:

a first specific frequency component detecting unit (2a; 79) for detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line (6a; 73);

a first intensity detecting unit (80) for detecting information on an intensity of said first specific frequency component detected by said first specific frequency component detecting unit (2a; 79);

a polarization-mode dispersion controlling unit (220a; 241b) for controlling a polarization-mode dispersion quantity of said transmission line (6a; 73) such that the intensity of said first specific frequency component detected by said first intensity detecting unit (3a; 80) becomes the maximum; and

a chromatic dispersion controlling unit (224a; 241a) for controlling a chromatic dispersion quantity of said transmission line (6a; 73) such that the intensity of said first specific frequency component detected by said first intensity detecting unit becomes the maximum or the minimum.

12. The dispersion compensation controlling apparatus according to claim 11, wherein when said transmission optical signal is an RZ optical signal or an optical time division multiplex signal, said first specific frequency component detecting unit (2a; 79) detects a frequency corresponding to a bit rate or 1/2 of the bit rate as said first specific frequency component, and when said transmission optical signal is an NRZ optical signal, said first specific frequency component detecting unit (2a; 79) detects a frequency corresponding to 1/2 of the bit rate as said first specific frequency component.

13. The dispersion compensation controlling apparatus according to any one of claims 6, 9 or 11, wherein said polarization-mode dispersion controlling unit [(220a; 90), (220a; 91), (220a; 241b)] sets a polarization-mode dispersion control quantity in a polarization-mode dispersion compensator [(7a; 4), (7a; 4), (7a; 4)] disposed in said transmission line [(6a; 3), (6a; 73), (6a; 73)] such that the intensity of said first specific frequency component detected by said first intensity detecting unit [(3a; 13), (3a; 80A), (3a; 80)] becomes the maximum.

14. The dispersion compensation controlling apparatus according to claim 13, wherein said polarization-mode dispersion controlling unit [(220a; 90), (220a; 91), (22a; 241b)] comprises:

a polarization-mode dispersion quantity detecting unit (14, 81, 81C) for detecting a polarization-mode dispersion quantity of said transmission optical signal from the intensity of said first specific frequency component detected by said first intensity detecting unit [(3a; 13), (3a; 80A), (3a; 80)] by using a first function which is a function representing an intensity of a frequency component in a baseband spectrum in an optical waveform forming an arbitrary transmission optical signal and in which said frequency information and parameters showing a polarization-mode dispersion quantity are variables; and

a parameter setting unit (15, 82, 82) for outputting a parameter setting control signal having parameter information as a control quantity for compensating polarization-mode dispersion of said transmission optical signal on the basis of said polarization-mode dispersion quantity detected by said polarization-mode dispersion quantity detecting unit (14, 81, 81C) to said polarization-mode dispersion compensator [(7a; 4), (7a; 4), (7a; 4)].

15. The dispersion compensation controlling apparatus according to claim 13 further comprising:

a third specific frequency component detecting unit (12b) for detecting a third specific frequency component in the baseband spectrum in said transmission optical signal; and

a third intensity detecting unit (13b) for detecting information on an intensity of said third specific frequency component detected by said third specific frequency component detecting unit (12b);

said polarization-mode dispersion controlling unit (220a; 1M) comprising:

a polarization-mode dispersion quantity detecting unit (14) for detecting a polarization-mode dispersion quantity of said transmission optical signal from the intensity of said first specific frequency component and the intensity of said third specific frequency component detected by said first intensity detecting unit (3a; 13a) and said third intensity detecting unit (13b), respectively, by using a first function which is a function representing an intensity of a frequency component in a baseband spectrum in an optical waveform forming an arbitrary transmission optical signal and in which said frequency information and parameters showing a polarization-mode dispersion quantity are variables; and

a parameter setting unit (15) for outputting a parameter setting control signal having parameter information

as a control quantity for compensating polarization-mode dispersion of said transmission optical signal on the basis of said polarization-mode dispersion quantity detected by said polarization-mode dispersion quantity detecting unit (14) to said polarization-mode dispersion compensator (7a; 4).

- 5 16. The dispersion compensation controlling apparatus according to claim 14 or 15, wherein said parameter information is at least either a delay quantity ( $\Delta\tau$ ) between two polarization modes or a splitting ratio ( $\gamma$ ) of an optical intensity to said two polarization modes.
- 10 17. The dispersion compensation controlling apparatus according to claim 14 or 15, wherein said parameter setting unit (15) outputs a parameter setting control signal for setting said parameter information to said polarization-mode dispersion compensator (7a; 4) disposed in a receiving terminal apparatus (7) which is a receiving terminal of said transmission optical signal.
- 15 18. The dispersion compensation controlling apparatus according to claim 14 or 15, wherein said parameter setting unit (15) outputs a parameter setting control signal for setting said parameter information to a polarization-mode dispersion compensator disposed in a transmitting terminal apparatus (10A) transmitting said transmission optical signal or a repeating apparatus (214) amplifying and repeating said transmission optical signal.
- 20 19. The dispersion compensation controlling apparatus according to claim 14 or 15, wherein said parameter setting unit (15) outputs a first parameter setting control signal for setting a splitting ratio ( $\gamma$ ) of an optical intensity to two polarization modes to a first polarization-mode dispersion compensator (7a; 4) disposed at an arbitrary position in a transmission line (6a; 3), and outputs a second parameter setting control signal for setting a delay quantity ( $\Delta\tau$ ) between said two polarization modes to a second polarization-mode dispersion compensator (7a; 4A) arranged in a rear stage of said first polarization-mode dispersion compensator (7a; 4B).
- 25 20. The dispersion compensation controlling apparatus according to claim 14 or 15 further comprising:  

a compensation quantity optimization controlling unit (31) for superimposing a predetermined low frequency signal set in advance on the parameter setting control signal outputted from said parameter setting unit (37) and controlling a parameter setting in said parameter setting unit (37) such that said low frequency signal component included in the intensity of said first specific frequency component from said first intensity detecting unit (3a; 30) becomes zero so as to optimize a compensation quantity of polarization-mode dispersion of said transmission optical signal.
- 35 21. The dispersion compensation controlling apparatus according to claim 20, wherein said compensation quantity optimization controlling unit (31A) superimposes two low frequency signals having low frequency components different from each other as said predetermined low frequency signal on said parameter setting control signal, controls a setting of a splitting ratio ( $\gamma$ ) of an optical intensity to two polarization modes in said parameter setting unit (37) such that either one of said two low frequency signal components included in the intensity of said first specific frequency component from said first intensity detecting unit (3a; 30) becomes zero, and controls a setting of a delay quantity ( $\Delta\tau$ ) between said two polarization modes in said parameter setting unit (37) such that the other one of said two low frequency signal components included in the intensity of said first specific frequency component from said first intensity detecting unit (3a; 30) becomes zero.
- 40 22. The dispersion compensation controlling apparatus according to claim 21, wherein said compensation quantity optimization controlling unit (31B) switches a setting control on the splitting ratio ( $\gamma$ ) of an optical intensity to said two polarization modes and a setting control on the delay quantity ( $\Delta\tau$ ) between two polarization modes with respect to time, and performs said setting controls.
- 45 23. The dispersion compensation controlling apparatus according to claim 14 or 15 further comprising:  

a sweep controlling unit (56) for largely sweeping and controlling the parameters showing said polarization-mode dispersion quantity to be given by said polarization-mode dispersion compensator (54) when a system is actuated or the system is re-actuated.
- 50 24. The dispersion compensation controlling apparatus according to any one of claims 6, 9 and 11, wherein said polarization-mode dispersion controlling unit (220a; 225) feedback-controls at least either a polarization controller (7a; 4B) or an inter-polarization-mode delay unit (7a; 227) disposed in said transmission line path (6a; 73) such that the
- 55

intensity of said first specific frequency component detected by said first intensity detecting unit (13) becomes the maximum.

- 5 25. The dispersion compensation controlling apparatus according to claim 24, wherein said inter-polarization-mode delay unit (7a; 227) is configured as a device splitting polarization-mode components by a polarization beam splitter (227a), giving a delay difference between said polarization-mode components by a variable optical delay path (227c) and multiplexing said polarization mode components.
- 10 26. The dispersion compensation controlling apparatus according to claim 24, wherein said inter-polarization-mode delay unit (7a; 230) is configured as a device in which a plurality of polarization maintaining fibers having different polarization dispersion values are arranged in parallel and said polarization maintaining fibers transmitting an optical signal are switched by an optical switch [230a (or 230b)] according to a polarization-mode dispersion quantity of said transmission line (6a; 73).
- 15 27. The dispersion compensation controlling apparatus according to claim 24, wherein said polarization-mode dispersion controlling unit (220a; 225) performs a control in a first control mode in which any one of an azimuth angle of a 1/4 wave plate (7a; 4B-11), an azimuth angle of a 1/2 wave plate (7a; 4B-12) in said polarization controller (7a; 4B) and a delay quantity between polarization modes of said inter-polarization-mode delay unit (7a; 227) is changed such that the intensity of said first specific frequency component becomes the maximum while the remaining control parameters among said azimuth angles and said delay quantity between polarization modes are fixed, after said first control mode, performs a control in a second control mode in which one of said remaining control parameters is changed such that the intensity of said first specific frequency component becomes the maximum while the control parameter having been first changed and the other one of the remaining control parameters are fixed, finally performs a control in a third control mode in which the other one of said remaining control parameters is changed such that the intensity of said first specific frequency component becomes the maximum while the control parameter having been first changed and the one of said remaining control parameters are fixed.
- 20 28. The dispersion compensation controlling apparatus according to claim 24, wherein said polarization-mode dispersion controlling unit (220a; 225) performs a control in a fourth control mode in which any one of an azimuth angle of a 1/4 wave plate (7a; 4B-11), an azimuth angle of a 1/2 wave plate (7a; 4B-12) in said polarization controller (7a; 4B) and a delay quantity between polarization modes of said inter-polarization-mode delay unit (7a; 227) is changed such that the intensity of said first specific frequency component increases while the remaining control parameters among said azimuth angles and said delay quantity between polarization modes are fixed, after said fourth control mode, performs a control in a fifth control mode in which one of the remaining parameters is changed such that the intensity of said first specific frequency component increases while the control parameter having been first changed and the other one of the remaining control parameters are fixed, finally performs a control in a sixth control mode in which the other one of said remaining control parameters is changed such that the intensity of said first specific frequency component increases while the control parameter having been first changed and the one of said remaining control parameters are fixed, after that, repeatedly executes said fourth control mode, said fifth control mode and said sixth control mode until the intensity of said first specific frequency component becomes the maximum.
- 30 29. The dispersion compensation controlling apparatus according to claim 24 further comprising a compensation quantity optimization controlling unit (241) for superimposing a predetermined low frequency signal set in advance on control signals to be outputted from said polarization-mode dispersion controlling unit (220a; 225a) to said polarization controller (4B) and said inter-polarization-mode delay unit (7a; 227), and controlling said polarization controller (7a; 4B) and said inter-polarization-mode delay unit (7a; 227) such that said low frequency signal component included in the intensity of said first specific frequency component from said first intensity detecting unit (3a; 13) becomes zero so as to optimize a compensation quantity of polarization-mode dispersion of said transmission optical signal.
- 35 30. The dispersion compensation controlling apparatus according to claim 29, wherein said compensation quantity optimization controlling unit (241) low-frequency-modulates an azimuth angle of a 1/4 wave plate (7a; 4B-11), an azimuth angle of a 1/2 wave plate (7a; 4B-12) in said polarization controller (7a; 4B) and a delay quantity between polarization modes of said inter-polarization-mode delay unit (7a; 227) with different frequencies, detects said first frequency component intensity in the baseband spectrum of said transmission optical signal, and optimizes the azimuth angle of said 1/4 wave plate (7a; 4B-11), the azimuth angle of said 1/2 wave plate (7a; 4B-12) in said polarization controller (7a; 4B) and the delay quantity between polarization modes of said inter-polarization-mode delay
- 40
- 45
- 50
- 55



unit (7a; 227) such that an intensity modulation component of a low frequency component included therein becomes zero.

- 5 31. The dispersion compensation controlling apparatus according to claim 24, wherein said polarization-mode dispersion controlling unit (220a; 225b) controls only said polarization controller (7a; 4B) during system operation, and controls said inter-polarization-mode delay unit (7a; 227) at the time of start of system operation or when an element determining conditions of polarization-mode dispersion in said transmission line (6a; 73) is switched.
- 10 32. The dispersion compensation controlling apparatus according to claim 24, wherein said polarization-mode dispersion controlling unit (220a; 225c) comprises a maximum allowable polarization-mode dispersion quantity setting means (212) for setting a maximum allowable polarization-mode dispersion quantity, sets a delay quantity of said inter-polarization-mode delay unit (7a; 230) to a value above a lower limit value defined as a value obtained by subtracting said maximum allowable polarization-mode dispersion quantity from one time slot and below an upper limit value defined as a value having a magnitude twice said maximum allowable polarization-mode dispersion quantity during system operation when feedback-controlling at least either said polarization controller (7a; 4B) or said inter-polarization-mode delay unit (7a; 230) disposed in said transmission line (7a; 73) such that an intensity of a frequency component corresponding to 1/2 of a bit rate as said first specific frequency component detected by said first intensity detecting unit (3a; 13) becomes the maximum.
- 20 33. The dispersion compensation controlling apparatus according to claim 32, wherein said polarization-mode dispersion controlling unit (220a; 225c) sets a delay quantity of said inter-polarization-mode delay unit (7a; 227) at the time of system operation to said lower limit value.
- 25 34. The dispersion compensation controlling apparatus according to claim 32, wherein said polarization-mode dispersion controlling unit (220a; 225c) sets a delay quantity of said inter-polarization-mode delay unit (7a; 230) at the time of system operation to said upper limit value.
- 30 35. The dispersion compensation controlling apparatus according to claim 24, wherein said inter-polarization-mode delay unit (7a; 230) is configured with a polarization maintaining fiber.
36. The dispersion compensation controlling apparatus according to claim 24, wherein said inter-polarization-mode delay unit (7a; 230) is configured with an inter-polarization-mode variable delay unit in a state where a delay quantity is fixed.
- 35 37. The dispersion compensation controlling apparatus according to any one of claims 6, 9 and 11 further comprising a timing extracting unit (84, 84, 84) for extracting a timing of a received signal on the basis of said first specific frequency component detected by said first specific frequency component detecting unit [(2a; 12), (2a; 79), (2a; 79A)].
- 40 38. The dispersion compensation controlling apparatus according to claim 9, wherein said chromatic dispersion controlling unit (224a; 240) sets a chromatic dispersion control quantity in a chromatic dispersion compensator (206a; 83) disposed in said transmission line (6a; 73) such that the intensity of said second specific frequency component detected by said second intensity detecting unit (223a; 80B) becomes the maximum or the minimum.
- 45 39. The dispersion compensation controlling apparatus according to claim 38, wherein said chromatic dispersion controlling unit (224a; 240) comprises:
  - a chromatic dispersion quantity detecting unit (81B) for detecting a chromatic dispersion quantity of said transmission optical signal from the intensity of said second specific frequency component detected by said second intensity detecting unit (223a; 80B) by performing an operation with a predetermined second function; and
  - 50 a chromatic dispersion control quantity setting unit (82B) for setting a chromatic dispersion control quantity in said chromatic dispersion compensator (206a; 83) on the basis of said chromatic dispersion quantity detected by said chromatic dispersion quantity detecting unit (81B) in order to compensate chromatic dispersion of said transmission optical signal.
- 55 40. The dispersion compensation controlling apparatus according to claim 9, wherein said chromatic dispersion controlling unit (224a; 240) feedback-controls a chromatic dispersion compensator (206a; 83) disposed in said transmission line (6a; 73) such that the intensity of said second specific frequency component detected by said second intensity detecting unit (223a; 80B) becomes the maximum or the minimum.



41. The dispersion compensation controlling apparatus according to claim 11, wherein said chromatic dispersion controlling unit (224a; 241a) sets a chromatic dispersion control quantity in a chromatic dispersion compensator (206a; 83) disposed in said transmission line (6a; 73) such that the intensity of said first specific frequency component detected by said first intensity detecting unit (3a; 80) becomes the maximum or the minimum.

42. The dispersion compensation controlling apparatus according to claim 41, wherein said chromatic dispersion controlling unit (224a; 241a) comprises:

a chromatic dispersion quantity detecting unit (81c) for detecting a chromatic dispersion quantity of said transmission optical signal from the intensity of said first specific frequency component detected by said first intensity detecting unit (3a; 80) by performing an operation with a predetermined second function; and  
a chromatic dispersion control quantity setting unit (82B) for setting a chromatic dispersion control quantity in said chromatic dispersion compensator (206a; 83) on the basis of said chromatic dispersion quantity detected by said chromatic dispersion quantity detecting unit (81c) in order to compensate chromatic dispersion of said transmission optical signal.

43. The dispersion compensation controlling apparatus according to claim 11, wherein said chromatic dispersion controlling unit (224a; 241a) feedback-controls a chromatic dispersion compensator (206a; 83) disposed in said transmission line (6a; 73) such that the intensity of said first specific frequency component detected by said first detecting unit (3a; 80) becomes the maximum or the minimum.

44. The dispersion compensation controlling apparatus according to any one of claims 6, 9 and 11, wherein said first intensity detecting unit (3a; 80) can output information on the detected intensity of said first specific frequency component as a monitor signal.

45. The dispersion compensation controlling apparatus according to claim 9, wherein said second intensity detecting unit (223a; 80B) can output information on the detected intensity of said second specific frequency component as a monitor signal.

46. A dispersion compensation controlling method comprising the steps of:

a first specific frequency component detecting step of detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line;

a first intensity detecting step of detecting information on an intensity of said first specific frequency component detected at said first specific frequency component detecting step; and

a polarization-mode dispersion controlling step of controlling a polarization-mode dispersion quantity of said transmission line such that the intensity of said first specific frequency component detected at said first intensity detecting step becomes the maximum.

47. A dispersion compensation controlling method comprising the steps of:

a first specific frequency component detecting step of detecting a first specific frequency component in a baseband spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line;

a first intensity detecting step of detecting information on an intensity of said first specific frequency component detected at said first specific frequency component detecting step;

a polarization-mode dispersion controlling step of controlling a polarization-mode dispersion quantity of said transmission line such that the intensity of said first specific frequency component detected at said first intensity detecting step becomes the maximum;

a second specific frequency component detecting step of detecting a second specific frequency component in the baseband spectrum in said transmission optical signal;

a second intensity detecting step of detecting information on an intensity of said second specific frequency component detected at said second specific frequency component detecting step; and

a chromatic dispersion controlling step of controlling a chromatic dispersion quantity of said transmission line such that the intensity of said second specific frequency component detected at said second intensity detecting step becomes the maximum or the minimum.

48. A dispersion compensation controlling method comprising the steps of:

5 a first specific frequency component detecting step of detecting a first specific frequency component in a base-band spectrum in a transmission optical signal inputted to a receiving side over a transmission fiber as a transmission line;

a first intensity detecting step of detecting information on an intensity of said first specific frequency component detected at said first specific frequency component detecting step;

10 a polarization-mode dispersion controlling step of controlling a polarization-mode dispersion quantity of said transmission line such that the intensity of said first specific frequency component detected at said first intensity detecting step becomes the maximum; and

a chromatic dispersion controlling step of controlling a chromatic dispersion quantity of said transmission line such that the intensity of said first specific frequency component detected at said first intensity detecting step becomes the maximum or the minimum.

15 49. The dispersion compensation controlling method according to claim 47 or 48, wherein said polarization-mode dispersion controlling step and said chromatic dispersion controlling step are independently executed.

50. The dispersion compensation controlling method according to claim 47 or 48, wherein said polarization-mode dispersion controlling step and said chromatic dispersion controlling step are executed in time series.

FIG. 1

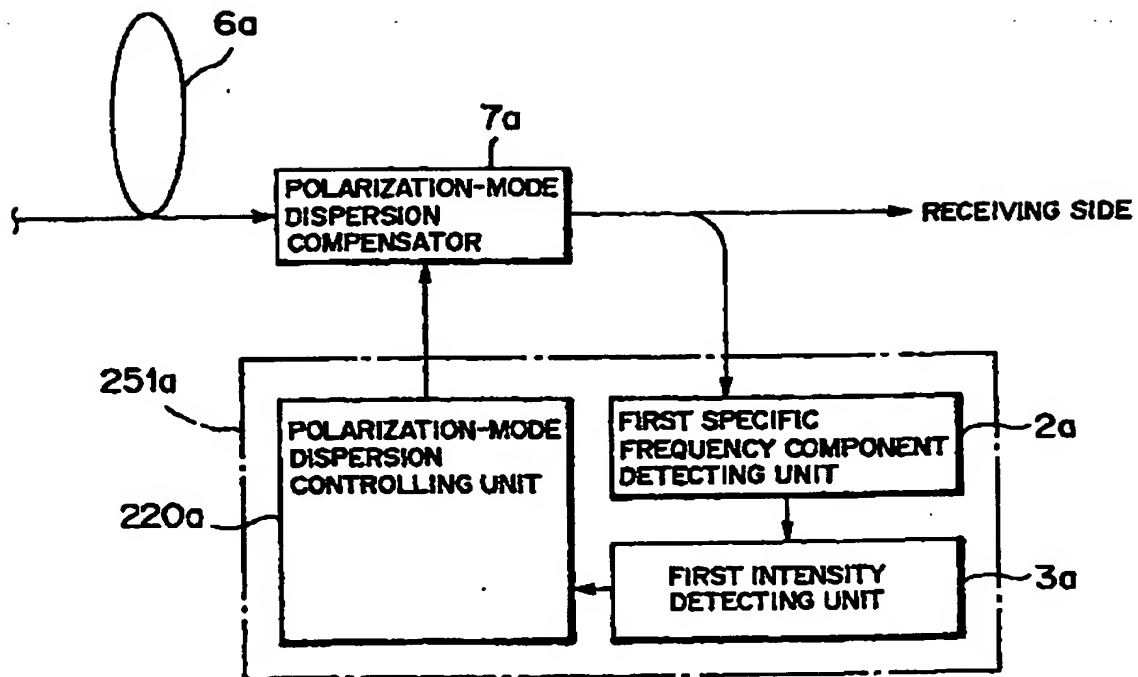


FIG. 2

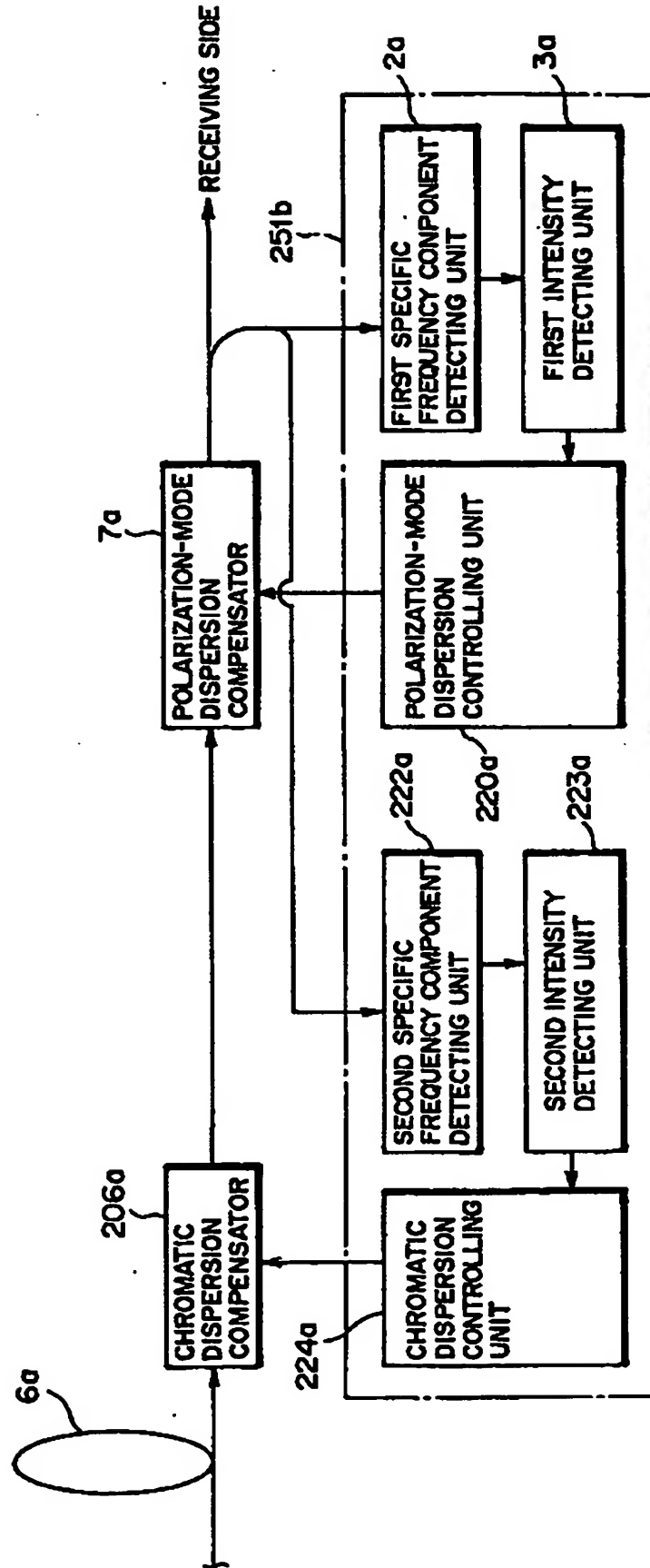


FIG. 3

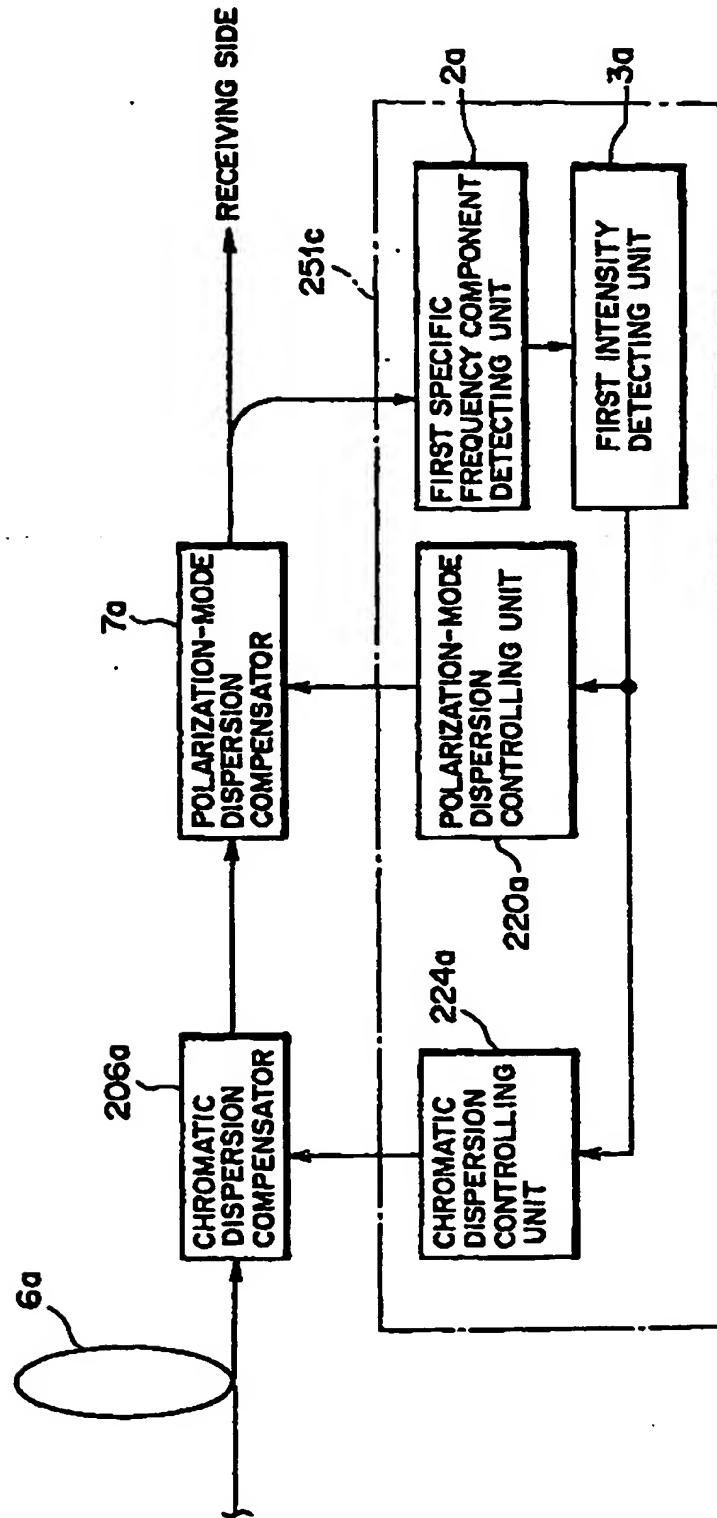


FIG. 4

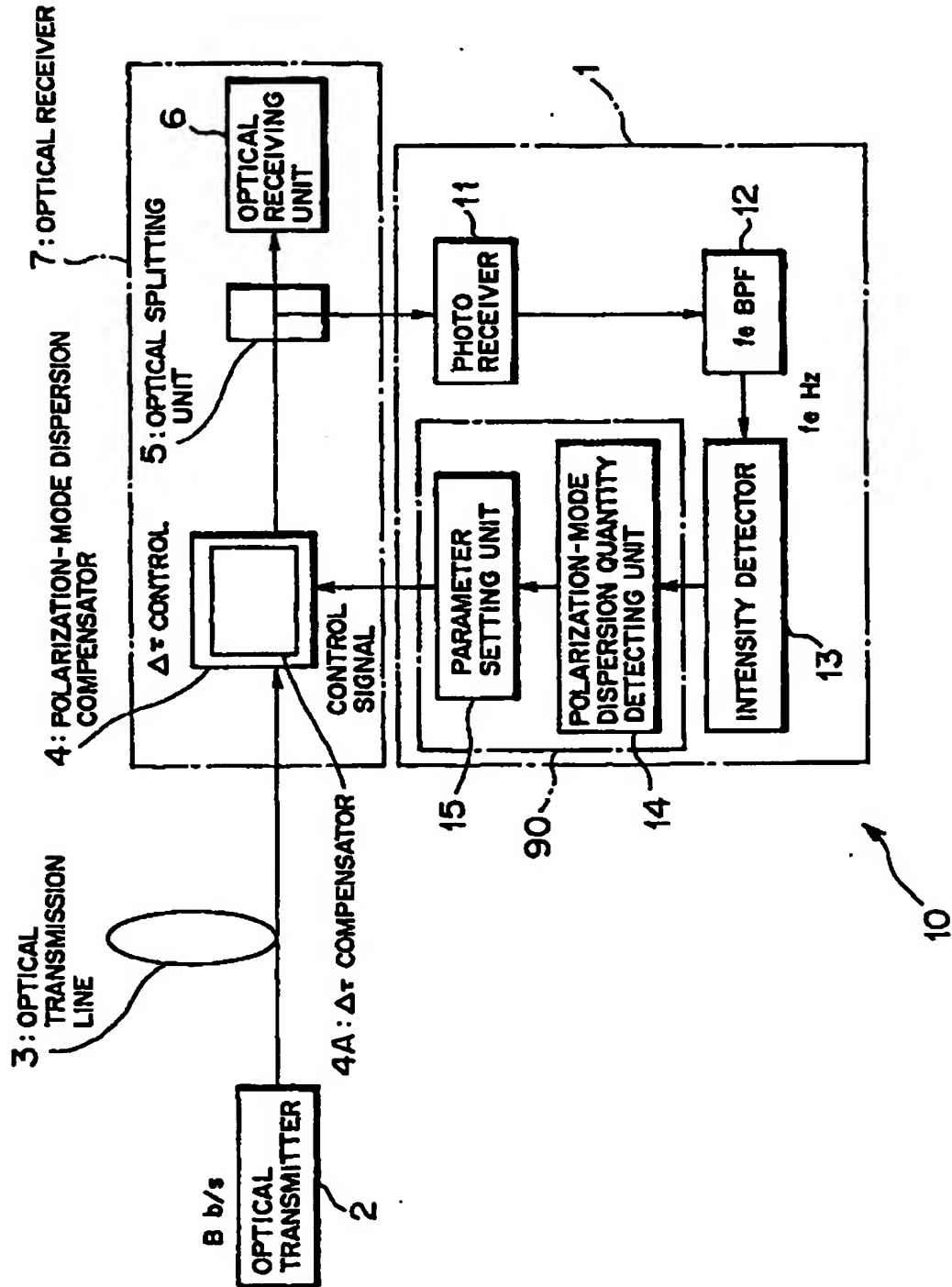


FIG. 5

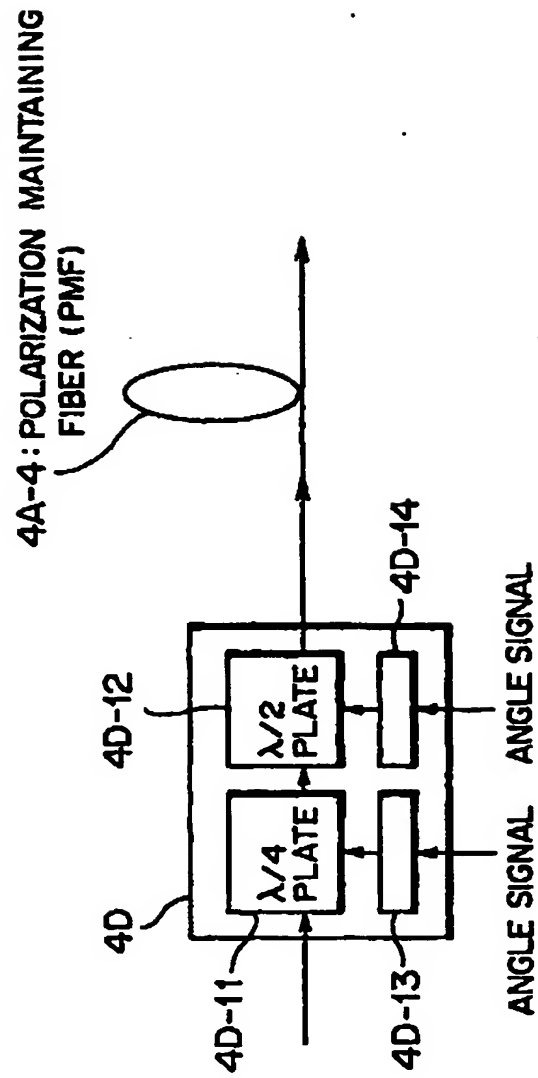




FIG. 6

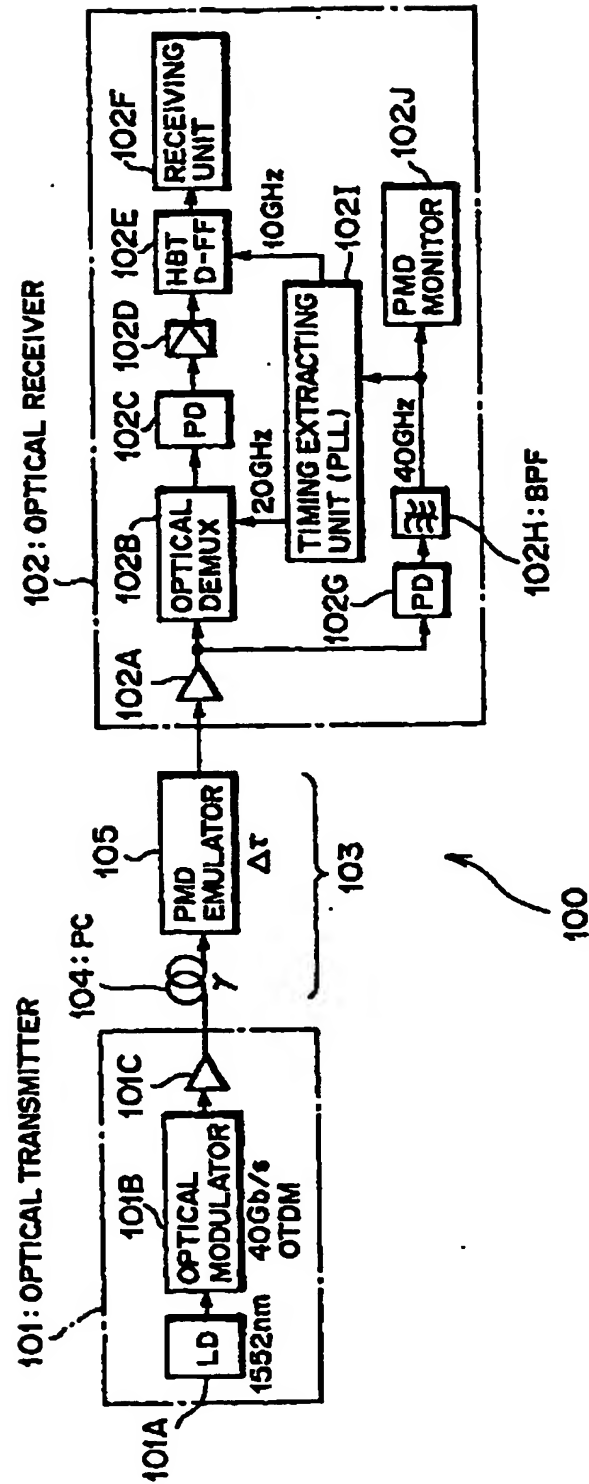


FIG. 7

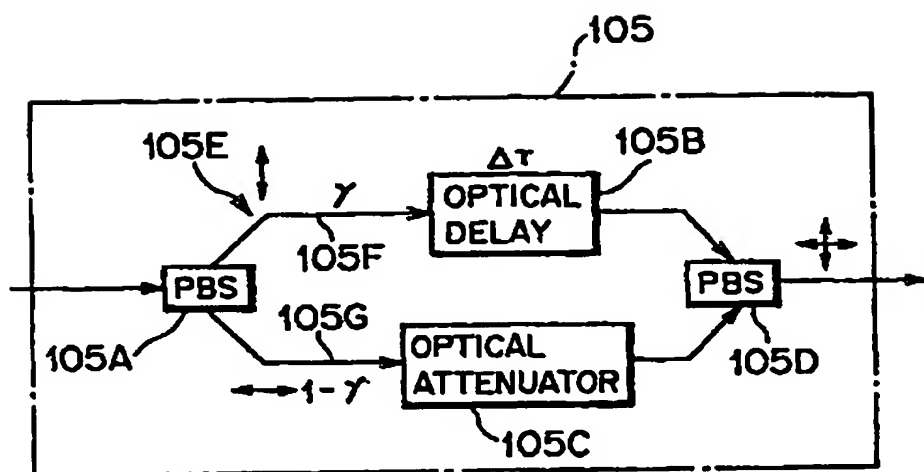


FIG. 7

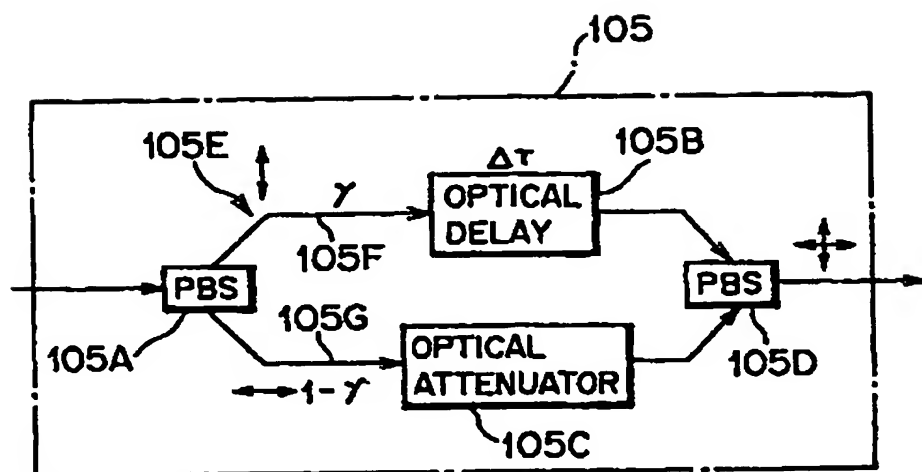


FIG. 8(a)

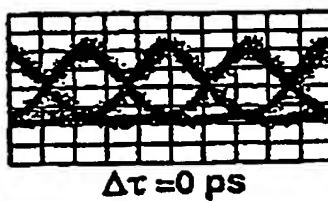


FIG. 8(b)

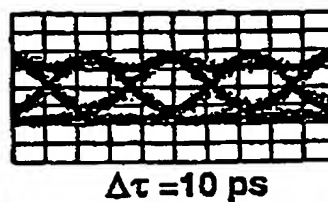


FIG. 8(c)

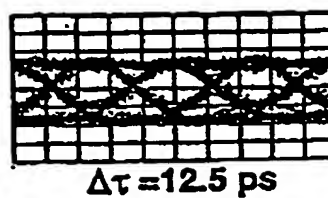


FIG. 8(d)

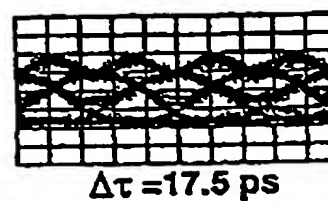


FIG. 8(e)

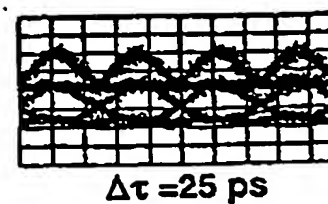


FIG. 20

